USE OF INFRARED RADIATION IN THE STUDY OF FISH BEHAVIOR

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EXPLANATORY NOTE

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United States Department of the Interior, Douglas McKay, Secretary
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ABSTRACT

Infrared radiation can be used to observe the actions of fish in the dark. Experiments demonstrated that the behavior of fingerling silver salmon (O. kisutch) was not affected by infrared radiation. The infrared filters used did not pass wavelengths visible to an observer, and the actions of the fish were observed through an infrared viewer. The fish were not attracted or repelled by steady radiation, and they did not exhibit a fright reaction to flashing radiation. The orientation pattern in still or flowing water was not affected; there was no indication that the fish could perceive the wavelengths employed.

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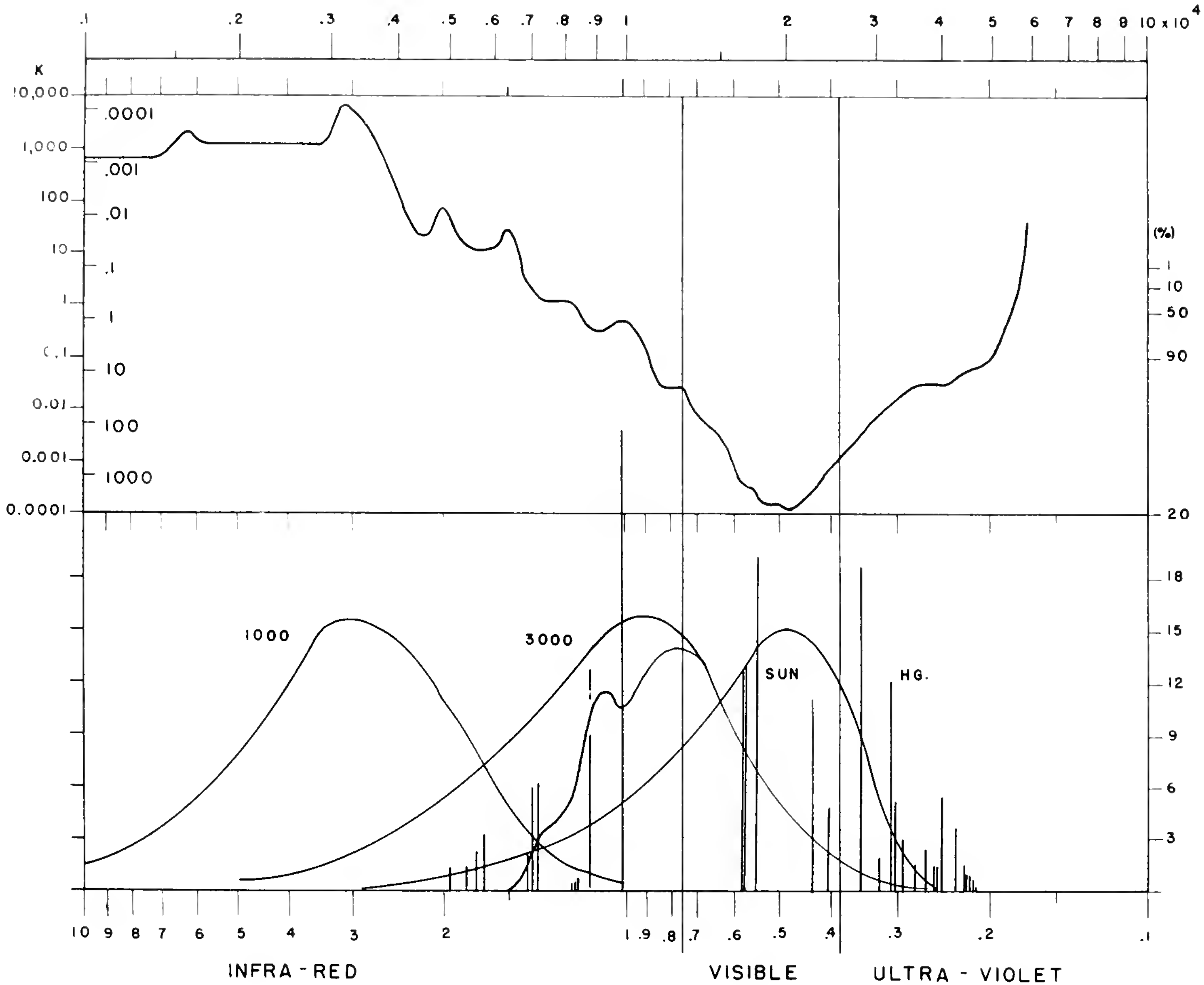

Figure 1
Radiation and Water Absorption

After Brockett, (1932)

EXPLANATION OF FIGURE 1

Upper Section: ABSORPTION

Water, ultraviolet, visible, and infrared.

Ordinates: Absorption coefficients k in $I = I_{oe}{-kx}$ (outside left).

Thickness transmitting half intensity in cm. (inside left)

Transmission of 1-cm, thickness (right).

Abscissae: Wavelengths in microns (bottom).

Wave numbers, waves per cm.(top).

Lower Section: RADIATION

Relative emission from body at 1, 000° K. (dull-red therapeutic lamp).

Relative emission from body at 3, 000° K. (high-temperature tungsten lamp).

Relative emission from sun.

The Eye and the Spectrum

Since near-infrared radiation may then be expected to penetrate the water sufficiently to be of use, it is pertinent to consider the relation of the spectrum to the vertebrate eye, with respect to a possible influence on behavior. The rods of the vertebrate eye furnish the hazy, black-and-white percepts of dim light, and the cones give the sharp, colored images of bright light. The rods are greatly aided in their scotopic (dark-adapted) function by the pigment rhodopsin, which in turn limits the spectral sensitivity of the rods to 650 m., at which wavelength rhodopsin becomes colorless and loses its photosensitivity. The cones alone perceive wavelengths greater than 650 m., and see them as red light. Walls (1942) notes that fish rhodopsin "in its shortening at the red end and in the position of its maximum is clearly adjusted to the kind of light in which it is to operate. It is thus no mere coincidence that the visible spectrum is roughly the transmission spectrum of water."

The ability to discriminate hue does not necessarily imply that the visible spectrum is thereby extended. Walls reviewed the color-vision work with fishes and other vertebrates done before 1942, and suggests a method (p.471) whereby the limit of an animal's spectrum may be determined: "By training to darkness versus a red wavelength, and increasing that wavelength slowly, the limit of the animal's spectrum can be found at that wavelength which, however intense physically, is invisible--at the border of (the animal's) infrared." Subsequent work has been done on the light reactions of fishes, but radiations used have not extended into the infrared wavelengths.

Infrared Radiation and Animals Other Than Fishes.

In lieu of data on the reaction of fishes to infrared radiation it may be well to consider the reactions of other animals in that regard. Luckiesh and Moss (1936) found with respect to the human eye that "infrared radiation apparently has no specific action upon the tissues analogous to that of abiotic or ultra-violet radiation."

Vanderplank (1934) reported that the tawny owl (Strix aluco) was able to find living animals in total darkness by the longwave infrared radiation from the body of the prey, and that the pupil of the owl's eye was contracted by hot-body infrared radiation. Matthews and Matthews (1949), working with the same species of owl and like radiation, found that an oscillograph and amplifying system could not detect a retinal potential and that any transmission through an extirpated eye was too small to measure with a thermopile. Hecht and Pirenne (1940) found that "infrared radiation (750-1500 m.) produces no iris contraction in the typically nocturnal long-eared owl." Dice (1945) studied four species of owls and discovered no evidence that they could utilize infrared radiation to find their prey.

Gunter (1951) employed both the discrimination method involving trained animals and the pupillo-motor response criterion in working with cats. He reports that the animals could not discriminate between darkness and infrared radiation, and that a pupillo-motor response was not observed when the dark-adapted cat's eye was directly stimulated with infrared radiations.

Vision in the infrared spectrum has been claimed for three species of water tortoises (Wojtusiak, 1949; Wojtusiak and Mlynarski, 1949). It should be noted that the filters used passed wavelengths of from 700 to 750 m., which are considered within the red range of the visible spectrum.

Southern, Watson, and Chitty (1946) used an infrared sensitive telescope with

a filtered car headlamp to study the brown rat at night. They concluded that "There seems no evidence at all that the brown rats are capable of detecting the rays."

The reported biological effects of infrared radiation thus do not preclude its use as a tool for observation. Confirmation is required for individual species, but there is some basis for such experiments.

Materials

The viewing equipment used in the following experiments was a telescope utilizing an electron-image tube with an associated optical system. The electron-image tube (Zworykin and Morton, 1936) consists of a photosensitive cathode, a fluorescent screen, and an electron optical system to focus upon the screen the electrons from the cathode. Two types of infrared telescopes are shown schematically in figure 2.

An electron optical system enjoys a distinct advantage over conventional optics, in that the brightness of the image can be increased to a higher level than that possessed by the subject. It is a characteristic of the image tube that the brightness of the reproduced image varies inversely with the square of the magnification of the tube, within limits of the size of the tube and the angular field of view (Morton and Flory, 1946). Observation with the viewer thus offers an additional advantage relative to information obtained by photographic means alone. Moreover, the brightened image may itself be photographed.

The electron-image tube requires a high-voltage power source, and the special power unit used was activated by a 6-volt battery. The light source used in the experiments was a 6-volt, 30-watt spotlight with a reflector and an infrared filter, operated from the same battery.

Experiments on the Reactions of Fish to Infrared Radiation.

The primary experiments in the main tank at the Fish and Wildlife laboratory in Seattle are concerned with the electrical guiding of fingerling salmon. These experiments are conducted in a darkened laboratory since much of the natural seaward migration is at night. The procedure further serves to eliminate light as a possible complicating factor in the experiments. Observation with infrared radiation then must not introduce a new complicating factor; reaction to the tool would preclude its use as detrimental to the guiding research.

An influence of infrared radiation might be manifest in the behavior of the fish in several ways. The fish might be attracted to the radiation or they might be repelled and seek to avoid it; they might use it to maintain orientation (particularly if their "visible" spectrum includes the wavelengths used); or they might be momentarily startled by the radiation.

Avoidance

A light-tight cover was constructed about an existing tank in the laboratory, with an enclosed area alongside the tank for an observer. The experimental facilities are diagrammed in figure 3. The tank was divided into two compartments by a wire-mesh gate that could be raised and lowered by the observer. The experimental area measured 72 by 80 inches, and consisted of two equal compartments, each 72 by 40 inches. The water depth was 3 inches, so that the bottom of the raised gate was submerged. The water was still. An overhead light was provided. A circular wire cage, 14 inches in diameter, which could be raised by the observer, restricted

INFRARED TELESCOPE

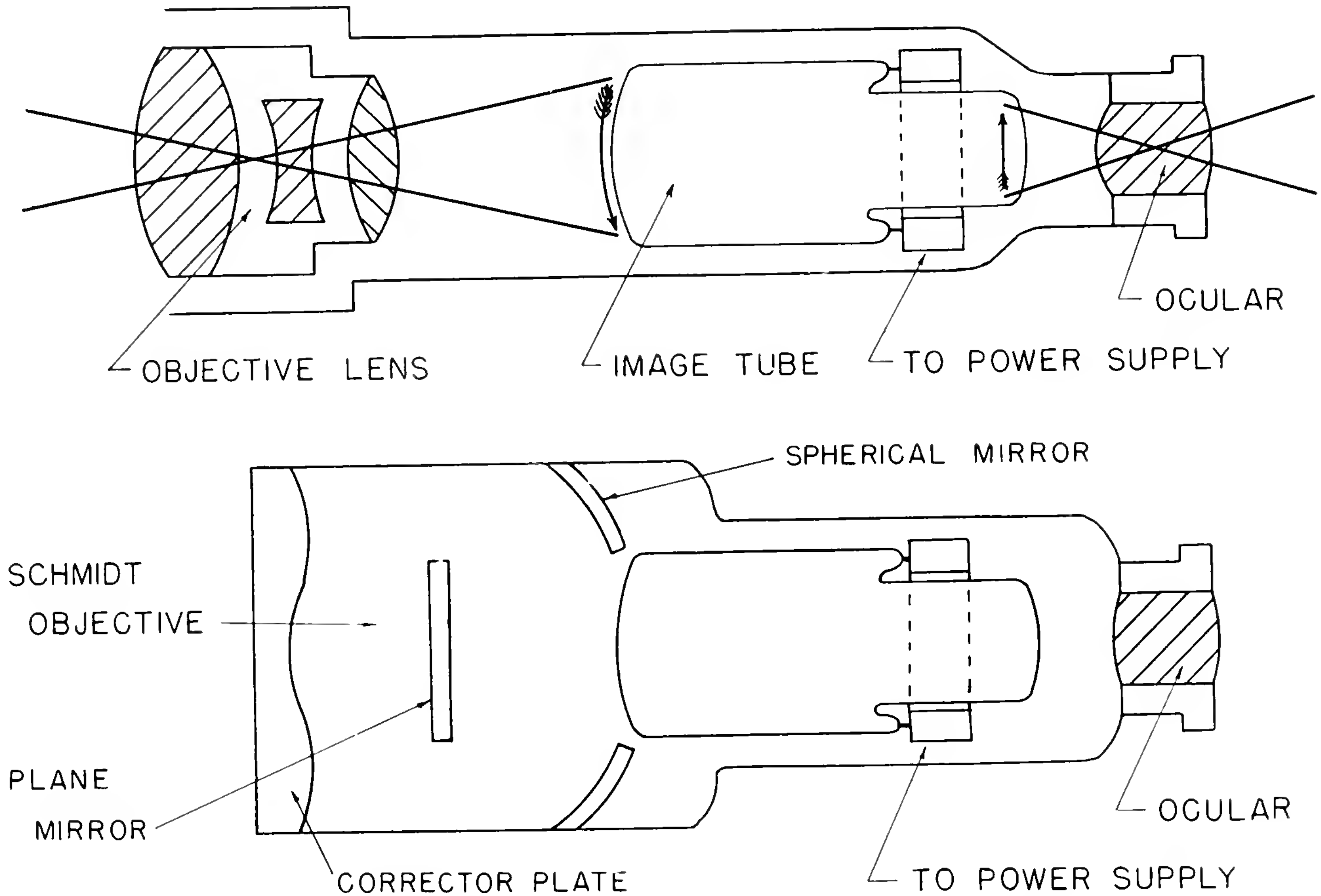

Fig. 2 Schematic diagram of two types of infrared telescopes.

After Morton & Flory (1946)

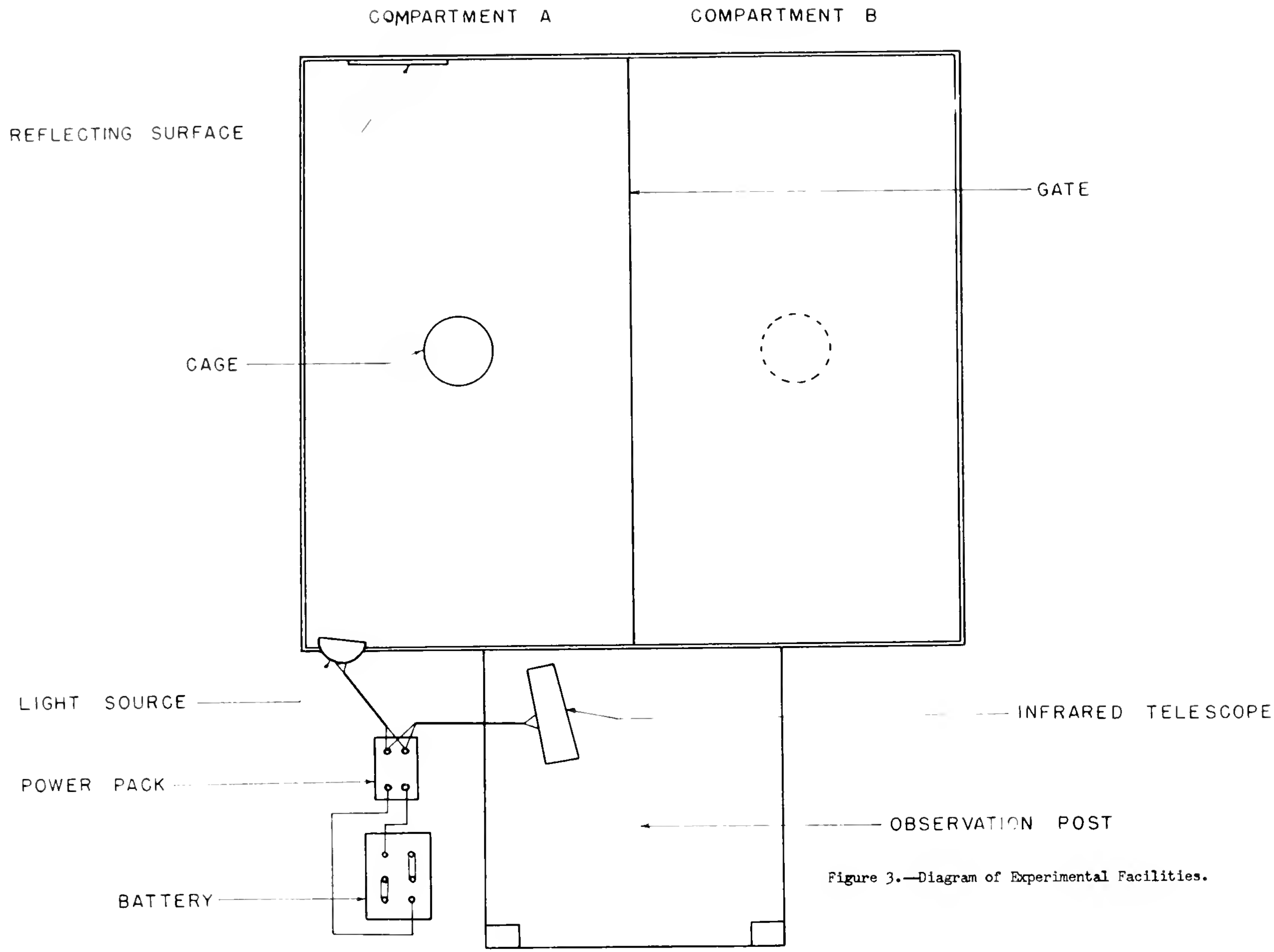

Figure 3.—Diagram of Experimental Facilities.

the movements of the fish and assured comparable distribution at the start of each test. It was placed in the center of compartment A, and raised 10 seconds before the beginning of test conditions. The infrared source was attached to the wall of the tank nearest the observer. It was located within compartment A, close to the outside wall so that any "escape" from the radiation must be in the direction of compartment B. A heavy black curtain shielded compartment B from the radiation in compartment A, although there was some light leakage under the gate. The beam was directed so that it met the surface of the water across the tank, and an additional reflecting surface--a board painted white--was provided at that point. The same source, with filter removed, was employed in the "light" part of the experiment.

Fingerling silver salmon (Oncorhynchus kisutch) of a size range from 7 to 11 cm. (total length) were used in the experiment. They were unconditioned fish which had not previously been exposed to the electrical fields of the guiding experiments.

Reactions of the fish were observed under three conditions: (1) infrared radiation, (2) visible light, and (3) darkness. A random sequence of conditions was not required, since separate lots of 50 fish each were used in each trial. With the gate between compartments raised, and the overhead light burning, the fish were placed in the wire cage. The light was extinguished, and the tank was kept in darkness for 5 minutes. At the end of that time the cage was raised and the fish were released. Ten seconds were allowed to elapse, and the test phase was begun. At the end of 15 seconds of experimental conditions the gate was released, falling sharply. The overhead light was then turned on, and the fish in each compartment were counted.

Attraction

The fish might not seek to avoid the infrared radiation and react as in darkness, and still be influenced by the radiation. It may serve to attract them. For that reason, and to detect possible influences peculiar to one or the other compartment, the restraining cage was transferred to compartment B and the experiments repeated. The light source remained in compartment A, in its original position.

The results of six trials of each condition are shown in table 1.

It is evident from table 1 that the fish did not react differently to infrared radiation and to darkness. They remained unmoved under the infrared in one compartment, and they did not seek it from the other compartment; they were neither repelled or attracted by the infrared radiations.

Orientation

The schooling proclivity of young salmon, and other fishes, is commonly laid to a visual orientation facility. Such a reaction is difficult to measure, but may be readily observed and recorded. To that end a small tank, 3 by 3 feet, was placed in the photographic darkroom of the laboratory, the infrared source and a camera focused on the tank, and the infrared telescope placed handy for observation. The water depth was 4 inches. The school of young silvers shown in figure 4 formed under the overhead light of the room and was photographed on black and white film. With infrared the only radiation in the room, the school was observed through the telescope. Dispersal was complete in a matter

Table 1.--Influence of radiation in displacement of fingerling silver salmon (*O. kisutch*) in still water

Radiation	Average Number Remaining*	Range	X^2 (**)	P
Radiation and fish in same compartment:				
Visible	4.83	2-9	#38.33	0.01
Infrared	45.17	43-47	.167	.50
None	48.0	46-49	. . . . . .	. . . . .
Radiation in opposite compartment from fish:				
Visible	47.17	40-50	.009	.90
Infrared	44.5	42-47	.231	.50
None	47.83	45-48	. . . . . .	. . . . .

* Average of six trials, 50 fish per trial.

** H_0: Movement is not influenced by radiation (is the same as in darkness).

\# Highly significant.

of a few seconds after the overhead light was extinguished. The photograph shown in figure 5 was taken in total darkness on infrared film, with the infrared source focused on the tank and an infrared flash bulb used as an auxiliary "light" source. The exposure was 1/30 second at f/3.5.

Orientation in flowing water is also considered to be accomplished, at least in part, by visual means. Accordingly a trough 12 feet long was marked off in 15 numbered sections, with heavy black lines running across the bottom and up the sides at 8-inch intervals. Two purposes were served by the procedure: Reference points were provided for the fish; and a means was established of measuring whether orientation was maintained in darkness or under infrared illumination. The infrared beam was directed along the trough from above the overflow end. It did not illuminate the trough evenly, as seen through the telescope, but appeared brightest in the region from section 10 through section 6. The apparatus is shown in figure 6.

The photograph of figure 6 was taken under the conditions of the experiment, except that additional infrared radiation was supplied temporarily by a filtered 1,000-watt spotlight. The film used was the infrared-sensitive Kodak IR 135, and the exposure was 8 seconds at a stop opening of f/3.5. The closeup shown in figure 7 is presented to illustrate the use of black-and-white film with the infrared telescope. The photograph was taken through the view plate of the telescope on Ansco Superpan Press film with an exposure of 1/2 second

Figure 4.--Distribution of fingerling silver salmon (O. kisutch) under ordinary room lighting.

Figure 5.--Distribution of fingerling silver salmon (O. kisutch) with infrared the only radiation present.

Figure 6.--Trough used in flowing water experiments.

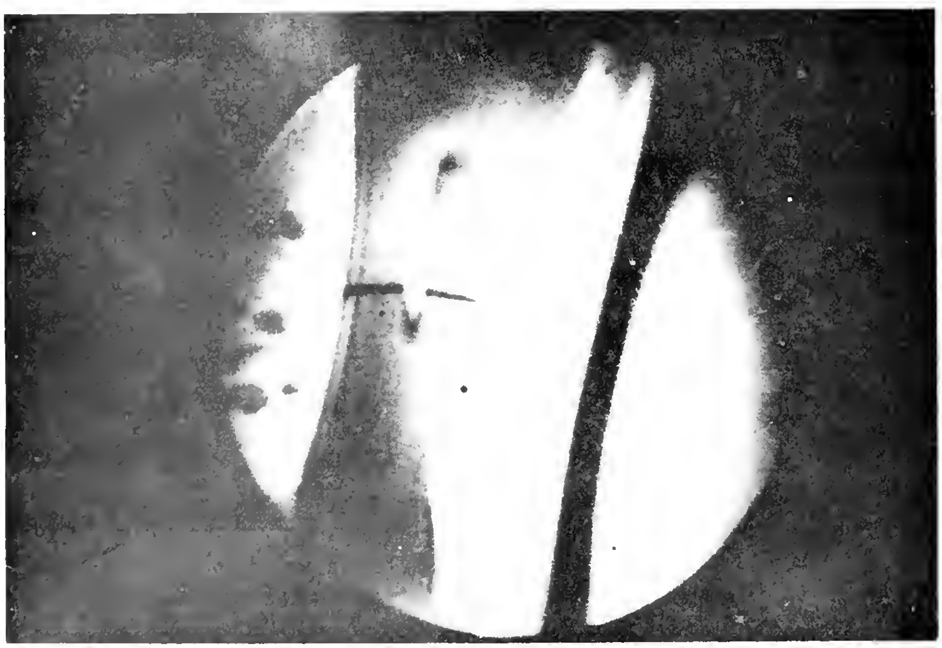

Figure 7.--Close-up view of trough and fish as seen through infrared telescope.

at a stop opening of f/4. Several fish are shown in the illustration, but single fish were used in the experiments.

Individual fish were used in the trough, and each was tested both in darkness and with infrared radiation. The fish were introduced in the light and allowed to swim freely about until they appeared to take up a definite position in relation to the current and the trough. When this position had been maintained for some 20 seconds, it was noted and the visible light turned out. The test situation, darkness or infrared, lasted for 1 minute, at which time the visible light was turned on and the position of the fish recorded. The results of the experiment appear in table 2.

There is nothing in the data from either orientation experiment to suggest that the young silver salmon are able to utilize infrared radiation to maintain their position, either with respect to other fish or to environment. The inference is, of course, that the necessary visual stimulation is lacking.

Fright

No evidence of a fright reaction was detected with the telescope when the fish were subjected to infrared radiation in the experiments just described. The matter was also examined specifically in comparison with visible light. The equipment used was the infrared source previously mentioned, a flashlight fitted with a Wratten 87 filter of the gelatin type, and an unmodified flashlight. The fish were in the hatchery holding troughs under subdued lights, and several observers were present. A typical fright reaction, with sudden, spasmodic movement and a rapid darting away from the light was noted when the visible light was directed on the fish and quickly turned on an off. All of the fish in the beam of light reacted similarly. When the flashlight with the gelatin filter was used it was noted that some of the fish reacted as above, but that others appeared completely unconcerned. Similar experiments after substitution of the regular infrared source failed to elicit an observable response.

The Wratten 87 filter was noticeably lighter than the other filter used, and a distinct red glow in the lens was noticeable upon looking directly into the light. No visible light could be seen in the beam or on the water. It would appear that fish so situated in the tank as to see the glow in the lens reacted to it, while those otherwise situated were unaffected. Walls (1942) notes that many fishes are sensitive to red, and that they "generally seem either to shun red, or to prefer it decidedly". Such evidently is not the case with infrared radiation, so far as the silver salmon tested were concerned.

INFRARED RADIATION AS A TOOL

Penetration in Water

Absorption by water is a problem in any use of infrared radiations for the observation of fish behavior. It has been noted in the upper part of figure 1 that penetration of the near-infrared wavelengths differs little from that of visible red, and is considerable. It has been further suggested that absorption, per se, is not the sole criterion of suitable penetration, and that the "visual range" of a light is almost double a corresponding Secchi-disk reading. In some situations the Rayleigh effect may be expected to increase the range of observations, and in all conditions visibility is improved by the brightening of the image in the image-converter tube. Illumination and penetration have proved adequate for work in the 9 inches of water in the main electrical-guiding pool at this laboratory, as illustrated in the photograph in figure 8.

Table 2.--Influence of infrared radiation on orientation of fingerling silver salmon (*O. kisutch*) in flowing water

	Position at beginning	Position at end	Displacement
Infrared radiation:			
Trial 1	2	8	6
Trial 2	3	2	+1
Trial 3	2	15	13
Trial 4	2	3	1
Trial 5	2	8	6
Trial 6	2	14	12
Trial 7	3	2	+1
Trial 8	2	15	13
Trial 9	2	4	2
Trial 10	2	14	12
Trial 11	2	14	12
Trial 12	2	9	7
Trial 13	2	15	13
Trial 14	1	12	11
Trial 15	1	8	7
Trial 16	1	10	9
Trial 17	2	6	4
Trial 18	2	5	3
Trial 19	2	12	10
Trial 20	2	3	1
Average	.....	.....	7.0
No radiation:			
Trial 1	3	15	12
Trial 2	2	2	0
Trial 3	2	5	3
Trial 4	3	13	10
Trial 5	2	4	2
Trial 6	4	8	4
Trial 7	3	2	+1
Trial 8	3	11	8
Trial 9	3	4	1
Trial 10	2	15	13
Trial 11	2	14	12
Trial 12	2	4	2
Trial 13	3	9	6
Trial 14	1	8	7
Trial 15	1	9	8
Trial 16	1	8	7
Trial 17	4	4	0
Trial 18	1	13	12
Trial 19	4	7	3
Trial 20	2	6	4
Average	.....	.....	5.65

Figure 8.--Fish and array in main guiding tank.

Figure 9.--Penetration of infrared radiation in water.

The picture was taken in total darkness with an infrared 22R flash, with an exposure of 1/30 second at a stop opening of f/3.5. Some indication of as yet unexplored possibilities is afforded by the penetration evidenced in the photograph in figure 9, taken at night off the laboratory dock. The markers are 1 foot apart. The exposure was 1/30 second at f/3.5 with the 22R infrared flash.

Animal Reaction

An examination of the literature has failed to yield evidence that fish or other animals possess the capacity to detect infrared radiations by visual means. Direct evidence as to whether other animals do detect them is scanty, and lacking for fishes. The gross experiments conducted in this laboratory with silver salmon (O. kisutch) failed to yield evidence that the fish could detect, or were affected by, infrared radiation. Individual species whose behavior is to be studied by this means should first be investigated for reaction to infrared radiation, but use of the tool is not precluded by *a priori* evidence.

Equipment

The ordinary high-temperature tungsten lamp delivers most of its energy in near-infrared radiation, in the infrared region of greatest penetration in water. Such lamps, screened by proper filters, may be used to provide any desired degree of intensity. The therapeutic infrared lamp is not suitable for observation of fish behavior because of the water-absorption characteristics of the wavelengths emitted.

Complete absorption of the visible spectrum by the filter is vital in fish-behavior studies, and for this reason filters suitable for darkness photography may fail when used over the light source. Suitable filters found military application and have been made available commercially.

Former military image-converter tubes and optical systems are also available, but must be assembled for use. Readily obtainable parts for the power units must likewise be assembled. In the absence of a viewer, indirect photographic observations may be made in the dark through the use of infrared film and suitable radiation.

Uses

There are many potential laboratory and aquarium applications of infrared radiation; behavior studies and direct observation of the habits of aquarium specimens may be readily extended by the observer being able to see in the dark. Questions concerning the importance of vision in orientation, for example, may be examined by observation rather than experimentation. Some diurnal-activity patterns can be established or confirmed.

The present laboratory use of infrared radiation in connection with electrical-guiding studies has an immediate extension into field use as the guiding apparatus is tested on a larger scale. Ultimately it may find employment at full-scale installations, and in each instance perhaps contribute to needed data.

The tendency of fingerling Pacific salmon to migrate seaward during the hours of darkness provides a wealth of opportunity for behavior studies under natural conditions. Among practical applications may be mentioned the possibly more precise and rapid locating of sampling devices.

Data are needed on the effectiveness of the location, size, and design of fishway orifices and the entrances to bypass channels Infrared radiation, with underwater television, could render service in observing undisturbed behavior at present installations, and supply information valuable in the design of future applications.

Commercial fishing, trawl operation in particular, could likewise profit from closer scrutiny at the level where reaction of the fish to the gear can mean the difference between success and failure of the operation. Increased knowledge of otherwise undisturbed behavior of the fish can lead to greater efficiency in both protection and utilization of fish resources.

Summary

Observation of fish behavior in the dark is possible through the employment of infrared radiation. The literature does not suggest that the visible spectrum of other animals extends further into the infrared wavelengths than that of man.

The reaction of fingerling silver salmon (Oncorhynchus kisutch) to infrared radiation was investigated with respect to attraction and avoidance, orientation, and fright. The experiments failed to yield evidence that the fish tested could perceive, or were affected by, infrared radiation.

Acknowledgments

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